Cylinder Wake Benchmark Specifications

Experimental Setup and Performance

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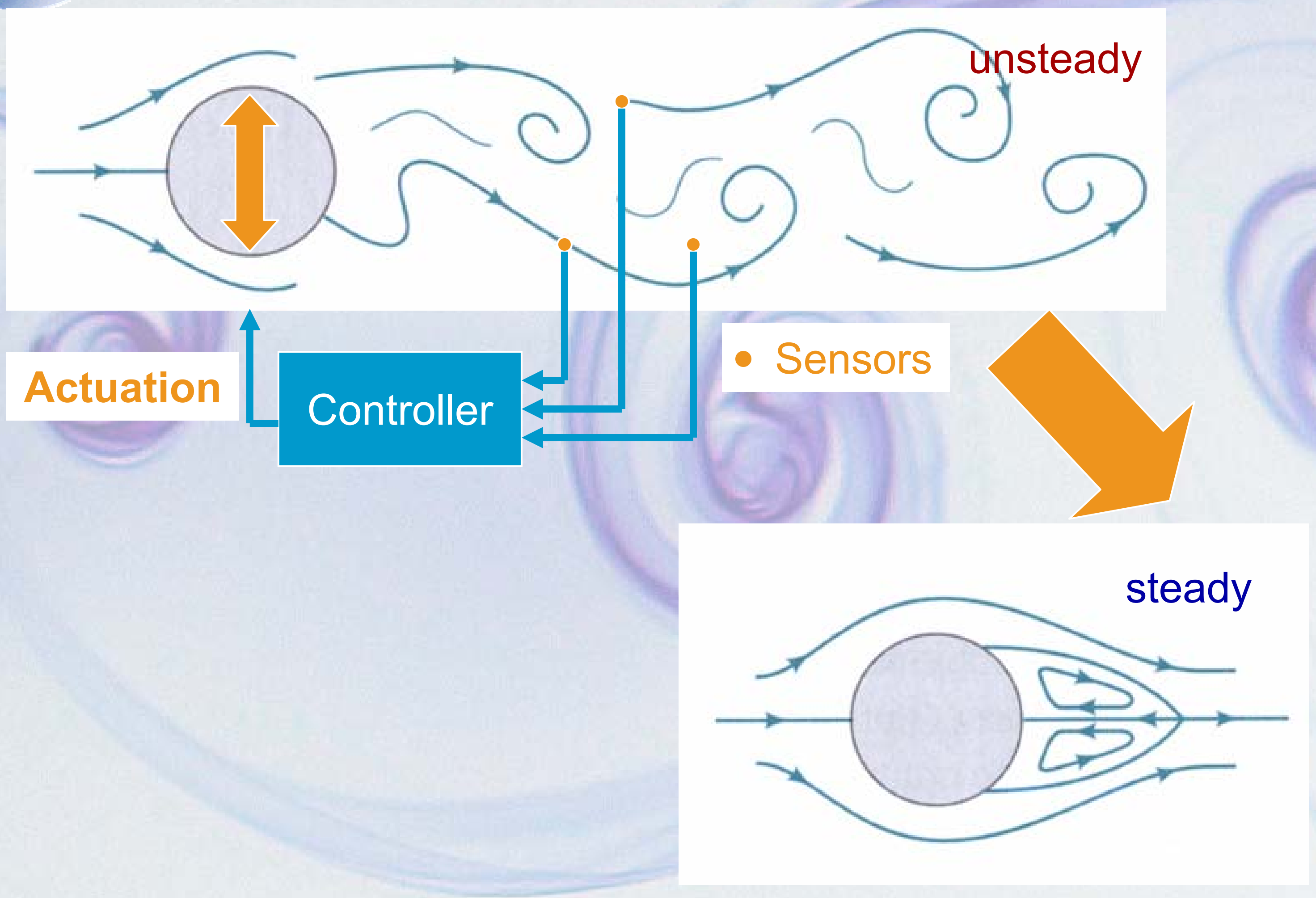
Why a Benchmark ?

- Feedback Flow Control requires a multi-disciplinary approach
- Lack of effective “plant” models that enable design of real-time estimation and control strategies
- For control community, investment in experimental infrastructure is substantial in terms of time, money and manpower

Sketch of Setup



Cylinder Wake Benchmark Specifications, August 2002

Sketches from: Munson, Young, Okiishi. *Fundamentals of Fluid Mechanics*. p 601.

Benchmark Goals

- Develop a benchmark that will enable the control specialist to engage in the problem without necessarily setting up an in-house multi-disciplinary team.
- Provide a forum for the application of a variety of control design methodologies.
- Develop a single experimental system, based on the existing infrastructure at USAFA, which will serve as an impartial T&E center for evaluating different strategies.
- Benchmark based on water-tunnel experiment of the cylinder wake, capable of translational motion, with real-time PIV for multi-sensor study.

Experiment Objectives

- Create a cylinder wake experiment suitable for feedback control including sensors, actuators and the model itself
- Provide Hardware and Software to integrate the experiment with MATLAB/SIMULINK

USAFA Circular Cylinder Wake Benchmark Specs

- Circular Cylinder Wake at Re = 120, $St_n \sim 0.16$
- Actuation through cylinder translation normal to mean flow
- Multi sensor capability
- Controller implementation in SIMULINK

$$Re = \frac{U_{inf} \cdot D}{\nu};$$

$$D = \text{Cylinder Diameter}$$

$$U_{inf} = \text{Freestream Velocity}$$

$$\nu = \text{Kinematic Viscosity}$$

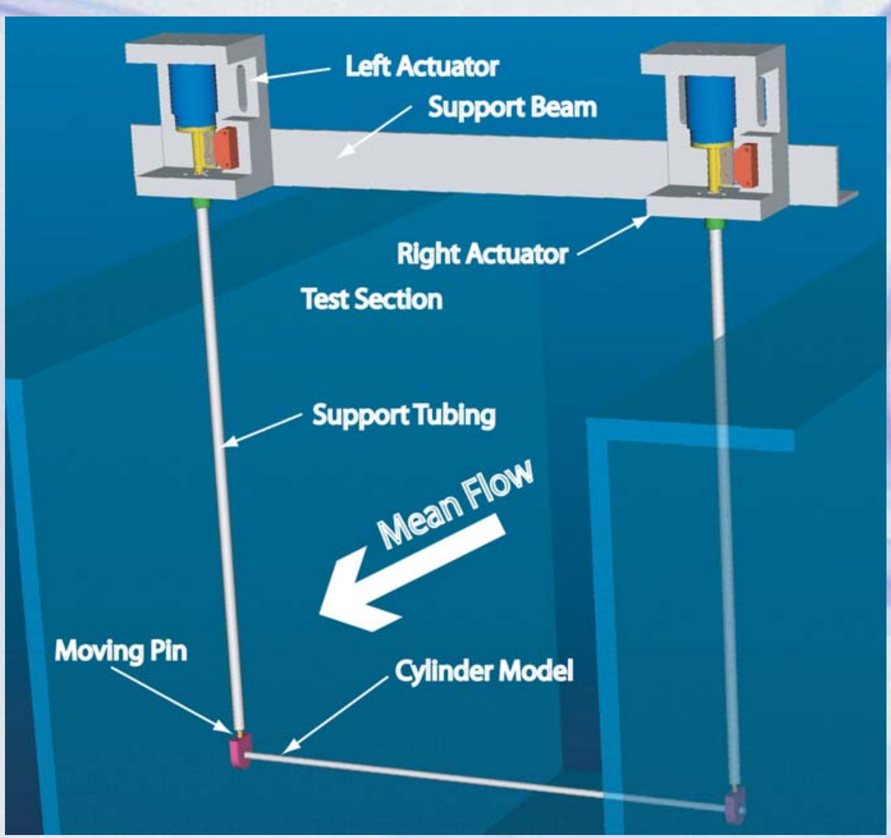
$$\nu_{H_2O} = 1 \cdot 10^{-6}$$

$$\nu_{Air} = 15 \cdot 10^{-6}$$

$$St = \frac{f \cdot D}{U_{inf}}$$

$$f = \text{Frequency}$$

Cylinder Model



- Cylinder Model: D = 3.97 mm
- Span: L = 381 mm
- => L/D ~ 95
- f_n = 1.22 Hz
- Vertical Travel: +/- 4 mm
- Bandwidth Actuators 50Hz +

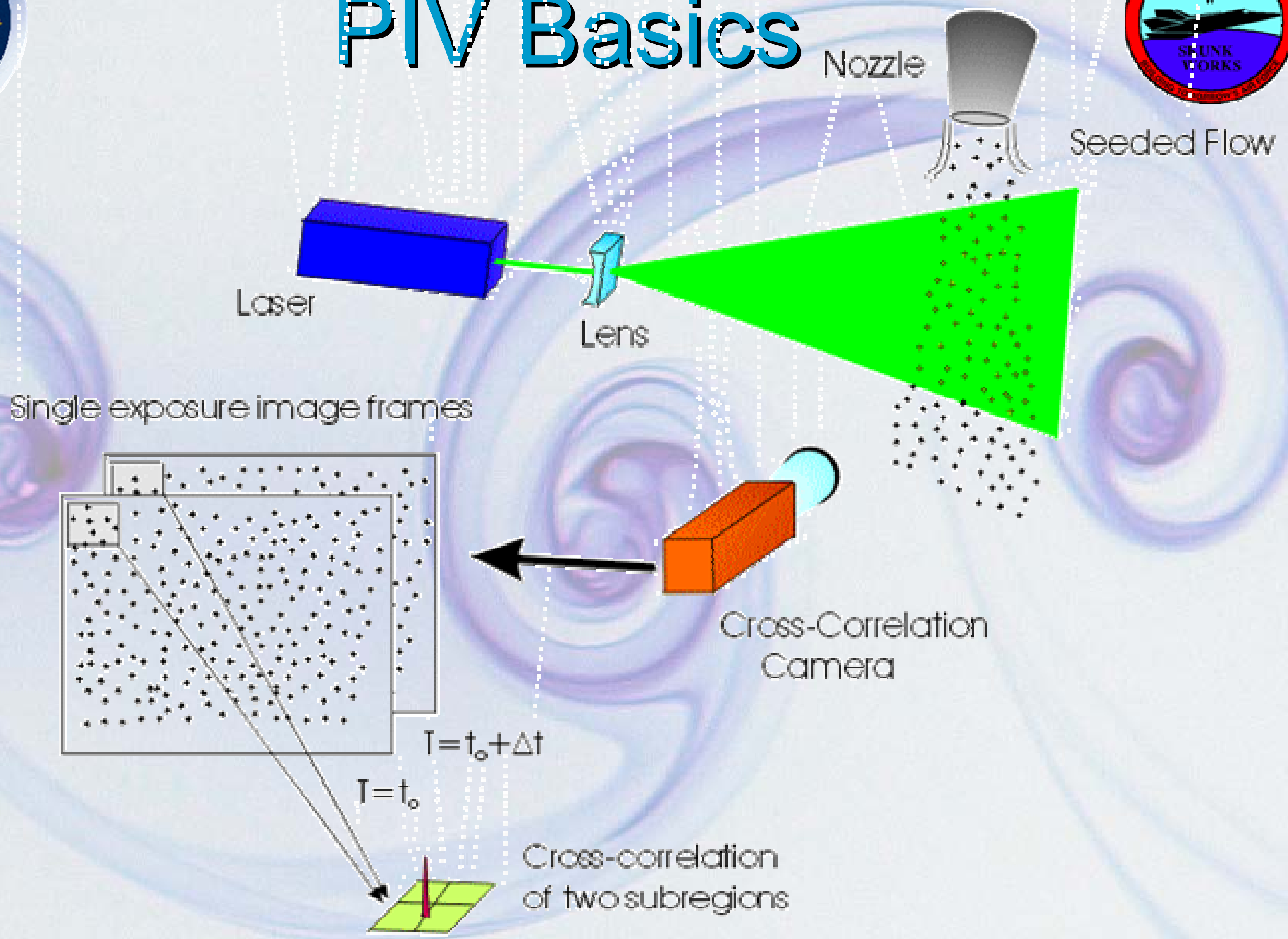
Water Tunnel Specs

- Eidetic Model 2436 Water Tunnel
  - U_{inf} = 25 mm/s to 300 mm/s
  - Flow Speed at Re = 120: ~30 mm/s
  - Natural Vortex Shedding Frequency ~1.22 Hz

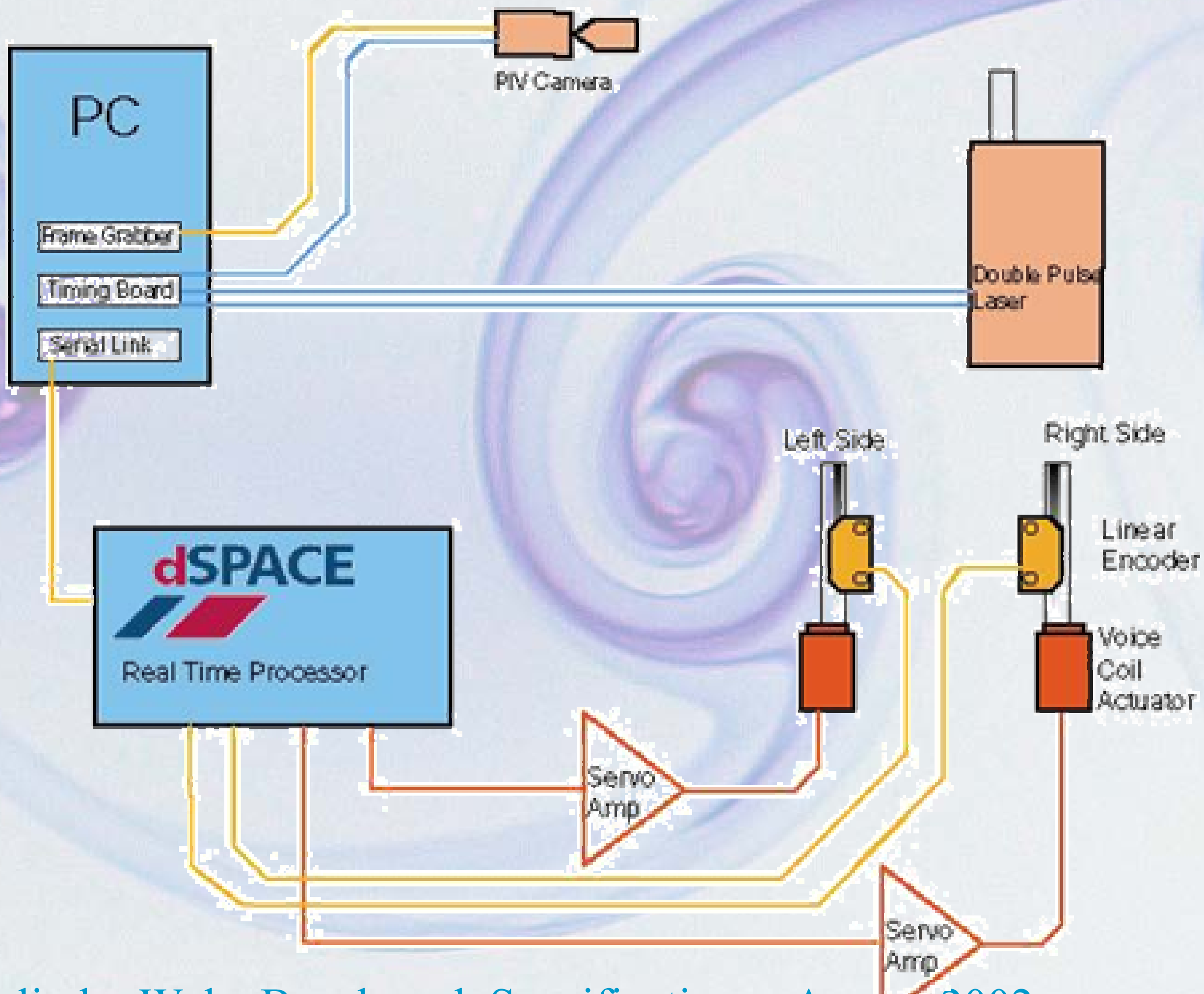
Real Time PIV System

- Pro's and Con's of Particle Image Velocimetry
  - + Many sensor locations
  - + Non-intrusive
  - + Separate velocity components
  - + Easy to calibrate and position
  - + moderately expensive
  - - Limited time resolution
  - - No real-time system commercially available, only off-line processing
- Currently, the only non-intrusive multi sensor capable measurement technique

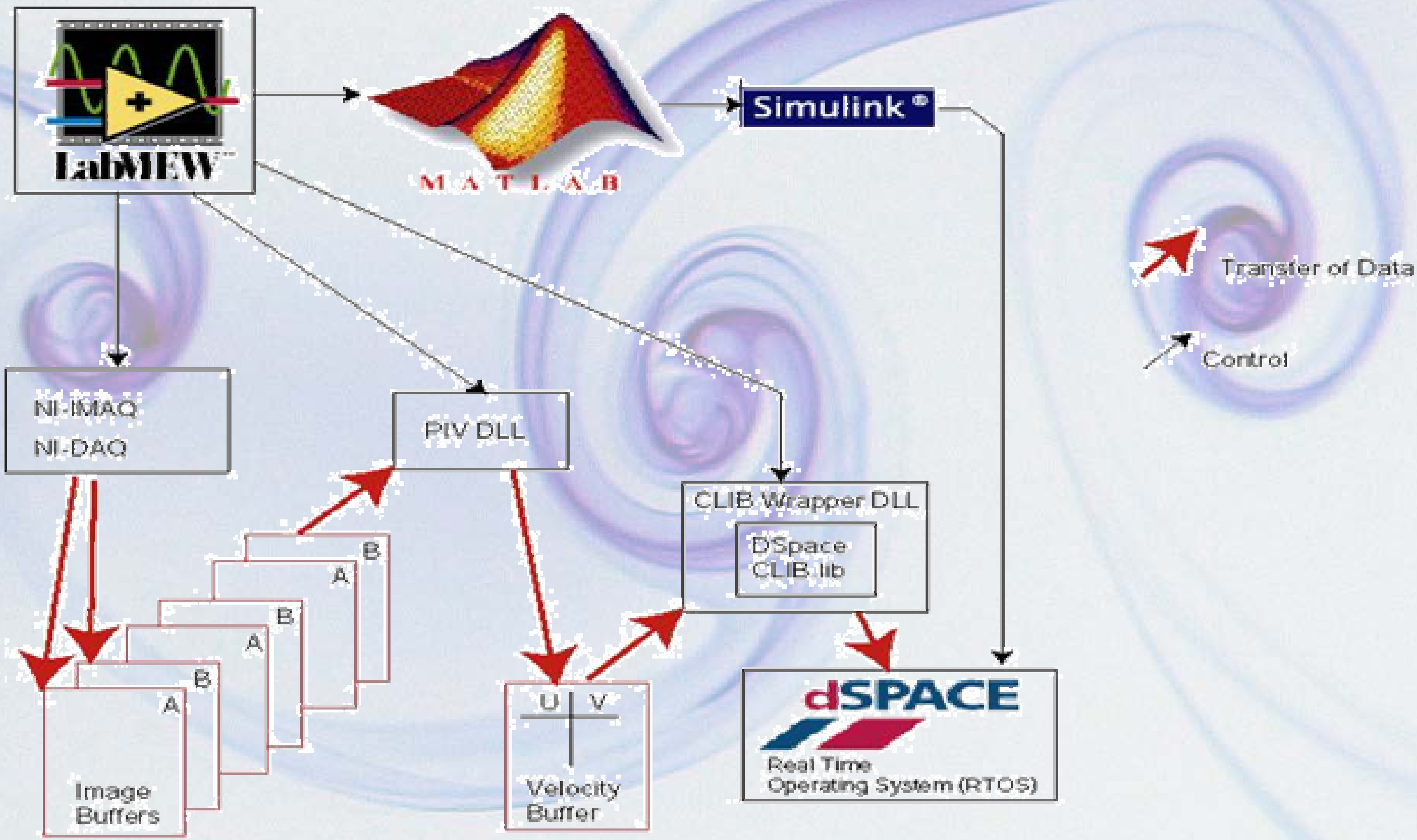
PIV Basics


Nozzle
Seeded Flow
Laser
Lens
Single exposure image frames
Cross-Correlation
Camera
$T=t_o+\Delta t$
$T=t_o$
Cross-correlation
of two subregions

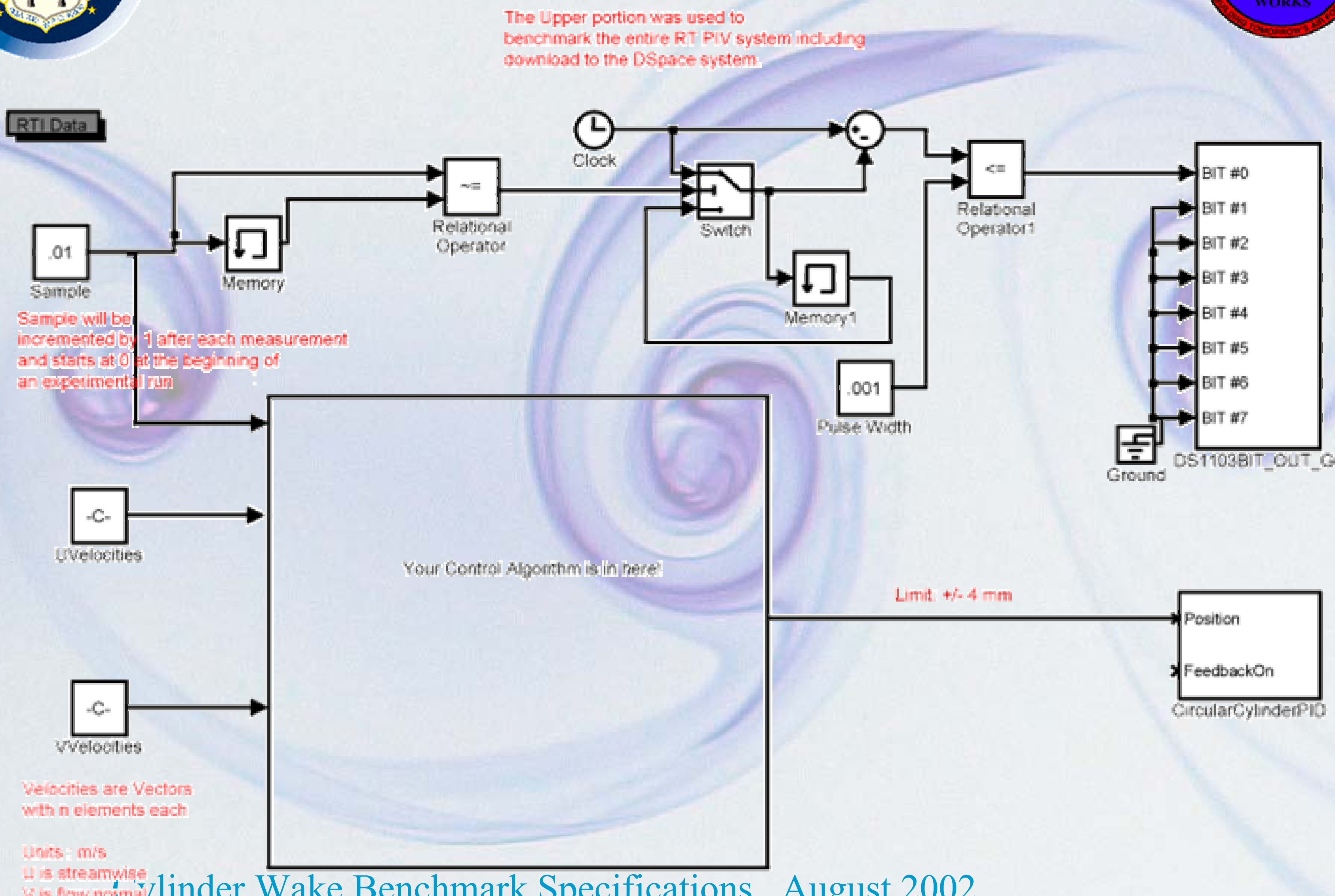
Benchmark Computer System



Software Layout



Simulink Template



PIV Tradeoffs

- Interrogation Area:
  - Large Interrogation Area -> small displacement measurement error. BUT: Small spatial resolution (i.e. few vectors throughout field of view
- Field of View
  - Large FOV shows entire flow field. BUT: Small spatial resolution, little detail on small flow structures

Typical PIV settings

- Delta T ~ 1 ms
- Particle displacement 4 – 8 pixels
- Interrogation Area 32 x 32 pixels
- Field of View 5 – 8 cylinder diameters

- => Velocity error about 2-5% U_{inf}
- => 30 x 30 velocity vectors
- => Spatial resolution (distance between vectors) about 0.16 – 0.26 cylinder diameters (with no overlap of interrogation areas)

PIV Performance Limits

- Camera Resolution: 1008 x 1016 pixels
- Maximum Frame Rate: 30 Hz
  - > 15 Hz Sampling of the flow field since two images are cross correlated
- Time delay to transfer Images from Camera to PC Memory: About 50 ms
- Time delay to correlate 6 Interrogation Areas and transfer data to DSpace RT Processor: 20 ms
- => total measured time delay 70 ms with a jitter of +/- 2 ms

Remarks on PIV Performance

- Larger interrogation areas will increase time delay
- More interrogation areas will increase the time delay
- We are working on quantifying these effects, the results will be presented at the AIAA meeting in Reno, 2003 (AIAA 2003-0920)
- Meanwhile, attempt to design a controller that is as robust as possible with respect to time delays

How to participate

- Develop a Control Algorithm.
- Determine number and placement (x, y) of your sensors.
- Make sure your controller is robust enough to tolerate the measurement time delay (Order of 10% of a shedding cycle).
- Schedule a visit to our lab and run your controller!

Contact, Questions???

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